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A SIGNATURE FOR ISOSCALAR-SPIN TRANSITIONS IN ($\vec{d}$,$\vec{d}$') SCATTERING

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Résumé - Trois signatures différentes pour les transitions isoscalaires de spin dans les noyaux ont été testées dans la réaction $^{12}C(\vec{d},\vec{d}')^{12}C$ à 400 MeV. Ces signatures sont proches de zero pour les niveaux de parité naturelle et varient de 0.22 à 0.5 pour le niveau 1^+ $\Delta T=0$ de 12.7 MeV.

Abstract - Three different signatures for isoscalar spin transitions in nuclei have been tested in the $^{12}C(\vec{d},\vec{d}')^{12}C$ reaction at 400 MeV. These signatures have values close to zero for the natural parity states, and ranging from 0.22 to 0.50 for the $\Delta S=1$ $\Delta T=0$, 12.7 MeV state.

1 - INTRODUCTION

Spin degrees of freedom have been extensively studied by charge exchange and inelastic scattering reactions /1,2/. In these reactions the transition is dominated by the isovector component of the spin interaction and the information obtained concerns essentially the isovector part of the spin response. The overall $\Delta S=1$ strength has been localized in a few nuclei /3,4,5/ by measuring the spin-flip probability S_{nn}. But, except for a few isolated states in s-d shell nuclei /6/, very little is known about the isoscalar spin strength distribution in nuclei. Informations on the isoscalar spin response are very useful in casting further ligth on the quenching mechanisms of spin transitions and on the non-observation of the enhancement of the longitudinal to transverse ratio in $(\vec{p},\vec{p}\,')$ experiments /7/. In order to search for $\Delta S=1$ isoscalar strength, a good isoscalar probe and a good signature similar to S_{nn} in $(\vec{p},\vec{p}\,')$ scattering /4/, of $\Delta S=1$ $\Delta T=0$ transitions in nuclei is needed.

2 - SIGNATURES OF $\Delta S=1$ $\Delta T=0$ TRANSITIONS

It has been shown /8/ that intermediate energy deuterons are a good isoscalar spin probe. At 200 MeV per nucleon, the ratio of the free nucleon nucleon t-matrices: t_{10}/t_{00} is maximum at zero momentum transfer (q=0) /9/. The vector and tensor analyzing powers A_y and A_{yy}, dominated by the nucleon-nucleon interaction, are characteristic of $\Delta S=0$ or $\Delta S=1$ transfer, but not sensitive enough to discriminate between the two spin transfers with a total confidence /1,2/. As in $(\vec{p},\vec{p}\,')$, spin-flip probabilities for the $(\vec{d},\vec{d}')$ scattering can be calculated /10/ namely:

$$S_0 = \frac{1}{6}[2 + 3K_y^{y'} + K_{yy}^{y'y'}]$$

$$S_1 = \frac{1}{9}[4 - A_{yy} - P^{y'y'} - 2K_{yy}^{y'y'}]$$

$$S_2 = \frac{1}{18}[4 + 2A_{yy} - 9K_y^{y'} + 2P^{y'y'} + K_{yy}^{y'y'}]$$

S_0, S_1 and S_2 are the probabilities to have a change of 0, 1 and 2 units in the spin projection along an axis taken normal to the scattering plane. Using the Madison conventions /11/ and following the notations of Ohlsen /12/, A_y and A_{yy} are the vector and tensor analyzing powers, $P^{y'}$ and $P^{y'y'}$ the vector and tensor polarization powers and $K_{ij}^{l'm'}$ the polarization transfer parameters. S_1 is similar to S_{nn} in $(\vec{p},\vec{p}\,')$ and it can be shown that it is zero for ΔS=0 transitions. S_1 involves the measure of the tensor polarization of the scattered deuterons. For ΔS=0 transitions we necessarily have S_2=0 and $P^{y'y'}=A_{yy}$. Then S_1 is equal to S_d^y defined by :

$$S_d^y = \frac{4}{3} + \frac{2}{3}A_{yy} - 2K_y^{y'}$$

S_d^y, is expected to be equal to zero for ΔS=0 transitions and positive for ΔS=1 transitions. Moreover S_d^y can be obtained with the use of a vector polarimeter like POMME /13/ which is available at the accelerator SATURNE. If the above relations are aproximatively true also for ΔS=1 transitions, S_d^y should have properties very similar to S_{nn} in $(\vec{p},\vec{p}\,')$. Two other signatures can also be defined :

$$T_d^y = P^{y'} - K_{yy}^{y'} \; and \; \Sigma_d^y = 1 - \frac{3}{2}K_y^{y'}$$

having values almost equal to zero for ΔS=0 transitions and $\neq$0 for ΔS=1. T_d^y is the difference of two odd functions of the scattering angle and may be weak also for ΔS=1 transitions. Σ_d^y is related to S_d^y and A_{yy} by : $\Sigma_d^y = \frac{3}{4}S_d^y - \frac{1}{2}A_{yy}$. Since S_d^y is expected to be zero and A_{yy} to be positive, Σ_d^y should be negative for ΔS=0 transitions. For ΔS=1 transitions A_{yy} is expected to be weak or negative and S_d^y positive, so Σ_d^y should be positive. Reinforced signatures ($S_d'^y$, $T_d'^y$ and $\Sigma_d'^y$) are obtained by multiplying the above signatures by $(1-A_y)(1-A_{yy})$. The reinforced signatures are expected to be close to the non reinforced ones for ΔS=1 transitions but to give a better cancelling for ΔS=0 transitions, then leading to a larger enhancement of the spin-flip strength relative to the non spin flip strength.

3 - EXPERIMENTAL TEST OF THE SIGNATURES

The signatures were tested on the three lowest natural parity states of ^{12}C, and on the well known ΔS=1 ΔT=0, 1^+ state at 12.71 MeV. The vector and tensor polarization parameters of the Saturne deuteron beam /14/ were regularly measured during the experiment. They were found to be very stable with a time-dependent drift of less than 0.01. The data were taken at the high resolution, energy-loss spectrometer SPES1 using the polarimeter POMME which has been previously calibrated /13,15/. The overall energy resolution was 280 keV. Measurements were performed at laboratory angles of 4°, 6° and 10°. For each peak, the spin-transfer parameters and the signatures were calculated after extracting the analyzing powers and measuring the polarization of the scattered deuterons for each of the four incident beam polarization states.

Table 1 *Normal and reinforced signatures for low lying states in ^{12}C. The second row of numbers coresponds to the errors in the signatures*

Signatures	S_y^d			T_y^d			Σ_y^d		
$\Theta_{lab.}$	4°	6°	10°	4°	6°	10°	4°	6°	10°
4.44 MeV	0.09 0.04	0.01 0.04	0.04 0.05	-0.10 0.02	-0.03 0.02	-0.09 0.02	-0.07 0.03	-0.11 0.03	-0.20 0.03
7.65 MeV	0.10 0.06	-0.06 0.05	0.13 0.03	-0.09 0.04	-0.06 0.03	-0.08 0.03	0.02 0.05	-0.14 0.04	-0.14 0.04
9.64 MeV	0.13 0.06	0.15 0.04	0.11 0.04	-0.08 0.03	-0.07 0.02	-0.10 0.02	-0.01 0.04	-0.03 0.03	-0.18 0.03
12.71 MeV	0.37 0.05	0.35 0.05	0.54 0.08	0.21 0.03	0.23 0.03	-0.09 0.05	0.33 0.03	0.28 0.04	0.33 0.06
Signatures	$S_y'^d$			$T_y'^d$			$\Sigma_y'^d$		
4.44 MeV	0.05 0.02	0.01 0.02	0.00 0.01	-0.06 0.01	-0.01 0.01	-0.01 0.01	-0.04 0.02	-0.05 0.01	-0.02 0.01
7.65 MeV	0.08 0.05	-0.02 0.01	0.02 0.01	-0.07 0.03	-0.02 0.01	-0.01 0.01	0.01 0.04	-0.04 0.01	-0.02 0.01
9.64 MeV	0.07 0.03	0.05 0.01	0.01 0.01	-0.04 0.02	-0.03 0.01	-0.01 0.01	-0.01 0.02	-0.01 0.01	-0.02 0.01
12.71 MeV	0.39 0.05	0.37 0.05	0.50 0.07	0.23 0.03	0.24 0.03	-0.08 0.04	0.35 0.04	0.29 0.04	0.30 0.05

The values for the three normal and reinforced signatures measured for the three $\Delta S=0$, 2^+, 0^+, and 3^- levels of ^{12}C and the $\Delta S=1$ 1^+ state at 12.71 MeV are given in table 1. Some details on data analysis are given in ref. /10/. For the $\Delta S=0$ transitions the signatures are small or negative. No systematic dependence of the signatures on details of the analysis was observed. For the 1^+ state at 12.71 MeV all the signatures have large positive values, excepted $T_d^{\prime y}$ at 10°. These values are comparable to those observed for S_{nn} in $(\vec{p},\vec{p}\,')$. As expected $T_d^{\prime y}$ is smaller than $S_d^{\prime y}$ and $\Sigma_d^{\prime y}$. For this state, $S_d^{\prime y}$ has the largest value. The results obtained at 4° (q=0.45 fm^{-1}) are given in Fig. 1.

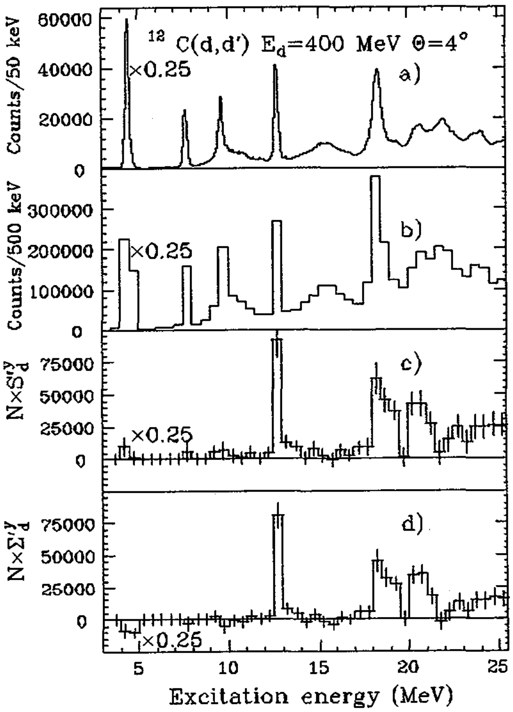

Fig. 1 - *Inelastic $(\vec{d},\vec{d}\,')$ spectrum measured at a laboratory angle of 4° on ^{12}C*

In this figure are plotted, as a function of the excitation energy in ^{12}C, a) the yield in counts per 50 keV bin, b) the same yield summed over 500 keV bins. This last yield multiplied by $S_d^{\prime y}$ or $\Sigma_d^{\prime y}$ are presented in Fig. 1-c and 1-d respectively. Comparison of Fig. 1-c and 1-d with Fig, 1-b, shows clearly that the 1^+ spin excitation at 12.71 MeV is strongly enhanced compared to the 2^+, 0^+ and 3^- $\Delta S=0$ states. Note that the spin-excitation strength is essentially zero in the 15 MeV region, where the 15.11 MeV isovector 1^+ is prominent in (p,p') spectra. The spin signatures make apparent the presence of spin strength above 18 MeV, especially in the region of the 18.3 MeV level and near 20.5 MeV. The 18.3 MeV level has been identified as a 2^-, T=0 state in a $(\vec{p},\vec{p}\,')$ spin-flip measurement /16/. The present results confirm that this is indeed an isoscalar spin excitation. Inelastic pion scattering work /17/ suggested a state at 20.0±0.2 MeV with a width of 3.2±0.3 MeV which was tentatively identified as the 1^- component of the T=0 spin-dipole resonance. The spectra shown in Fig. 1-c and 1-d are difficult to reconcile with the existence of this state, since they show a pronounced minimum at about 19.8 MeV. Nevertheless, they reveal considerable isoscalar spin strength above 20 MeV which is not reported in the compilation of ^{12}C levels /18/. The results obtained at 6° (q=0.7 fm^{-1}) and 10° (q=1.14 fm^{-1}) are given in Fig. 2. The comparison of the spin-flip-excitation spectra to the raw excitation spectrum confirms the conclusions of the 4° data analysis, the relative enhancement of the 12.7 MeV peak being particularly impressive at 10°. While the relative enhancement of the $\Delta S=1$ strength through the S_d^y signature does not change with increasing momentum transfer, the enhancement through the Σ_d^y becomes much weaker. This weakening of the enhancement with increasing momentum transfer is due on one hand to the fact that Σ_d^y becomes negative and increases in magnitude and, on the other hand, to the increase of the $\Delta S=0$ background.

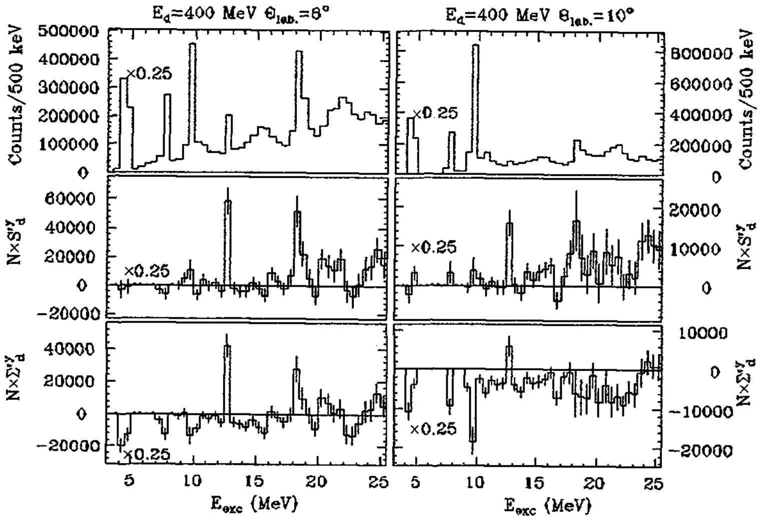

Fig. 2 - *Inelastic (d,d') spectrum measured at laboratory angles of 6° and 10° on ^{12}C*

4 - SUMMARY

We have proposed three different signatures for isoscalar spin transitions excited by $(\vec{d},\vec{d'})$ inelastic scattering. The normal S_d^y and Σ_d^y and the reinforced $S_d'^y$ and $\Sigma_d'^y$ signatures turn out to be very efficient in selecting $\Delta S=1$ transitions. Theoretical values for these signatures are still not available to compare with the present data. Nevertheless, the small or negative measured values of $S_d'^y$ and $\Sigma_d'^y$ for the different $\Delta S=0$ transitions certainly indicate that a large and positive value of $S_d'^y$ and $\Sigma_d'^y$ is a proof of the presence of spin transitions. At medium and high momentum transfer, the S_d^y signature appears to be the best to reveal $\Delta S=1$ strength in the continuum. This good signature of $\Delta S=1$ transitions added whith the good isoscalar selectivity of the $(\vec{d},\vec{d'})$ reaction gives us a very powerful tool for a selective search of the isoscalar spin strength. Plans are underway to use this method to locate isoscalar spin strength in other nuclei.

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